(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 035 671 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
13.09.2000 Bulletin 2000/37

(51) Int. Cl.[7]: H04B 10/18

(21) Application number: 00103973.4

(22) Date of filing: 25.02.2000

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 09.03.1999 JP 6234499

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(54) Dispersion Compensating optical transmission line and system

(57) A dispersion compensating optical transmission line (32) comprises a plurality of optical transmission fibers (38-1,38-2,...) for transmitting signal light, at least one first dispersion compensator (40-6) disposed at a first dispersion compensating cycle for compensating an accumulated chromatic dispersion of the signal light so that an average chromatic dispersion is equal to a first desired value (Davg×z), and a plurality of second dispersion compensators (40-1,40-2,...) disposed at a second dispersion compensating cycle shorter than the first dispersion compensating cycle for compensating the accumulated chromatic dispersion of the signal light so that an average chromatic dispersion is equal to a second desired value (Dlocal×z) which absolute value is larger than that of the first desired value.

FIG. 1 (A)

FIG. 1 (B)

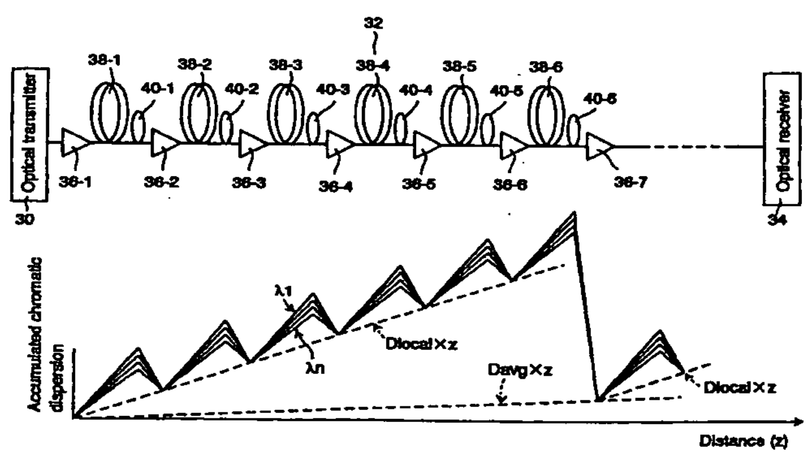

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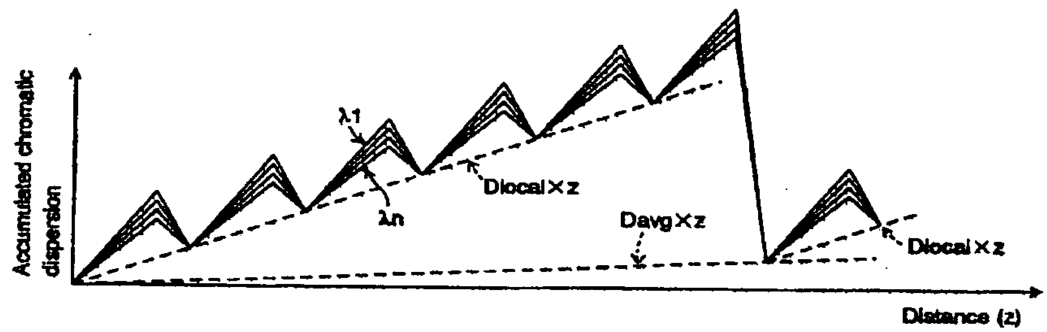
FIG. 1 (B)


Accumulated chromatic dispersion
λ1
λn
Dlocal×z
Davg×z
Dlocal×z
Distance (z)

[0009] A nonlinearity of an optical fiber is generally expressed as n_2/A_{eff}. The reference symbols n_2 and A_{eff} denote a nonlinear constant and an effective core area respectively. The nonlinearity n_2/A_{eff} of a SCDCF is larger than that of a standard single mode optical fiber. In a conventional system that the dispersion compensation fibers 26 are inserted at frequent intervals, the nonlinear effect, which affects the transmission characteristics, becomes larger. In order to perform the long haul transmission while balancing the nonlinear effect with the chromatic dispersion value, the chromatic dispersion value Davg after the dispersion compensation by the dispersion compensation fiber 26, namely the chromatic dispersion value of the whole system should be set relatively high.

[0010] As already mentioned above, because the nonlinear effect exists to no small extent in long haul transmission such as transoceanic transmission, the average chromatic dispersion value Davg of the whole system preferably should be a low value other than zero for balancing the nonlinear effect with the chromatic dispersion value.

[0011] In the conventional system shown in FIGS. 2(A) and 2(B), the dispersion-shifted fiber is employed as the optical transmission fiber. The chromatic dispersion value of the dispersion-shifted fiber is low at the 1.5 μm band and therefore the influence due to the nonlinearity becomes relatively too large. To put it concretely, in the WDM transmission, owing to the lowness of the local chromatic dispersion value at the interval before the dispersion compensation by the dispersion compensation fiber 16, each interaction length among the respective wavelengths becomes too long causing the large influence of cross phase modulation (XPM), which makes the stable long haul transmission impossible.

[0012] On the other hand, when a single mode fiber, which chromatic dispersion value is high at the 1.5 μm band, is employed as the optical transmission fiber 12, each interaction length among the respective wavelengths of the WDM signal light is shortened and thus the influence of the XPM is also suppressed. However, in order to control the accumulated chromatic dispersion value (the absolute value) within a predetermined value, the dispersion compensation fibers 14 should be inserted at shorter intervals. In other words, the dispersion compensating cycle should be shorter and consequently this configuration becomes more similar to that shown in FIG. 3(A).

[0013] In the conventional system shown in FIGS. 3(A) and 3(B), on account of employing the single mode optical fiber, which has the zero dispersion wavelength at the 1.3 μm band, as the optical transmission fiber 24, the local chromatic dispersion value becomes high. Accordingly, each interaction length among the respective wavelengths of the WDM signal light is shortened and thus the influence of the XPM is also suppressed. However, due to the frequent insertion of the dispersion compensation fibers 26, the nonlinear effect of the whole system grows large. When such a large nonlinear effect is balanced with the chromatic dispersion value, the chromatic dispersion value Davg after the dispersion compensation becomes excessively high. As a result, the large chromatic dispersion value, conversely, becomes a problem and makes the transmission characteristics deteriorated. Specifically, the troubles most likely to be occurred are jitter and dispersion endurance. These troubles are most serious in long haul transmission such as transoceanic transmission.

SUMMARY OF THE INVENTION

[0014] An object of the present invention is to provide an optical dispersion compensating transmission line and system for transmitting WDM signal light steadily over a long haul.

[0015] According to the present invention, at least one first dispersion compensator disposed at a first dispersion compensation cycle compensates an accumulated chromatic dispersion of signal light so that an average chromatic dispersion is equal to a first desired value and a plurality of second dispersion compensators disposed at a second dispersion compensating cycle shorter than the first dispersion compensating cycle compensate the accumulated chromatic dispersion of the signal light so that an average chromatic dispersion is equal to a second desired value which absolute value is larger than that of the first desired value.

[0016] By this configuration, satisfactory transmission characteristics can be obtained within the first dispersion compensating cycle as well as the control of the chromatic dispersion of the whole transmission system can be simplified.

BRIEF DESCRIPTION OF THE DRAWING

[0017]

FIGS. 1(A) and 1(B) show a schematic block diagram according to a first embodiment of the invention and a distance variation of its accumulated chromatic dispersion respectively;

FIGS 2(A) and 2(B) show a schematic block diagram of a conventional system and a distance variation of its accumulated chromatic dispersion respectively;

FIGS 3(A) and 3(B) show a schematic block diagram of another conventional system and a distance variation of its accumulated chromatic dispersion respectively;

FIG. 4 shows a schematic block diagram according to a second embodiment of the invention;

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 10 3973

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0777347 A	04-06-1997	JP 9162805 A	20-06-1997
		US 5966228 A	12-10-1999
FR 2761839 A	09-10-1998	JP 10276172 A	13-10-1998
		US 6181449 B	30-01-2001
GB 2309131 A	16-07-1997	JP 9191290 A	22-07-1997
		FR 2743637 A	18-07-1997
		US 5956440 A	21-09-1999
JP 08237222 A	13-09-1996	NONE	
EP 0701340 A	13-03-1996	JP 8139670 A	31-05-1996
		US 5629795 A	13-05-1997

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light, to the chromatic dispersion values of the dispersion compensation fibers 40-1~40-5 on the downstream side. By this configuration, when entering the dispersion compensation fibers 40-1~40-5, the signal light can avoid both sudden decline of its effective core area and sudden change of its chromatic dispersion value. The optical transmission fiber 38-6 disposed immediately before the dispersion compensation fiber 40-6 also should have the same configuration.

[0026] The WDM signal light output from the optical transmitter 30 is optically amplified at the optical repeating amplifier 36 while propagating on the optical transmission fiber 38 and dispersion compensation fiber 40, and finally enters the optical receiver 34. The dispersion compensation fiber 40 compensates the accumulated chromatic dispersion of each wavelength light (wavelengths $\lambda 1 \sim \lambda n$) as shown in FIG. 1(B).

[0027] The above configuration makes it possible to control the chromatic dispersion value Davg of the whole transmission system to be low while keeping the local chromatic dispersion value high. As a result, in the WDM transmission, each interaction length among the respective wavelengths can be shortened as well as the chromatic dispersions can be easily controlled, and consequently the total transmission characteristics are improved. In other words, the chromatic dispersion is balanced with the nonlinear effect from both macroscopic and microscopic views; microscopically, the transmission characteristics of the WDM signal light are improved by increasing the chromatic dispersion value and, macroscopically, the dispersion management becomes easier by controlling the excessive increase of the accumulated chromatic dispersion.

[0028] The following configuration is also applicable that the signal light is given a chromatic dispersion in a minus direction beforehand and output onto the optical transmission line. Accordingly, the signal light receives an effect similar to a phase modulation and thus it is not necessary to dispose a phase modulator at the optical transmitter or a phase modulation degree can be reduced even if a phase modulator is required. Furthermore, spectral spreading can be avoided and a channel interval can be narrowed. This is especially effective in an optical transmission system of long haul or ultra long haul such as transoceanic transmission.

[0029] FIG. 4 shows a schematic block diagram according to a second embodiment of the invention in which signal light receives a chromatic dispersion before it outputs onto an optical transmission line, and FIG. 5 shows a schematic diagram of a distance variation of a accumulated chromatic dispersion.

[0030] Reference numerals 50 and 52 denote an optical transmitter and optical receiver respectively, and 54 denotes, similarly to the optical transmission line 32, a dispersion compensating optical transmission line for compensating an accumulated chromatic dispersion of each wavelength with two kinds of dispersion compensating cycles.

[0031] The optical transmitter 50 comprises a signal light generator 56 for generating WDM signal light and a dispersion pre-compensating element 58 which gives a chromatic dispersion value of a minus direction to the output light from the signal light generator 56 and sends the signal light to the transmission line 54. Preferably, the chromatic dispersion value given to the signal light in advance by the dispersion pre-compensating element 58 should be more than half of the accumulated chromatic dispersion value of the optical transmission line 54.

[0032] The optical receiver 52 comprises a dispersion post-compensating element 60 for compensating the chromatic dispersion remained in the signal light propagated on the optical transmission line 54 and a signal light detector 62 for detecting a signal in the output light from the dispersion post-compensating element 60.

[0033] As explained above, the optical transmission line 54 has the same configuration with the optical transmission line 32. Namely, the optical transmission line 54 comprises optical transmission fibers 64, optical repeating amplifiers 66, first dispersion compensation fibers 68 inserted at first dispersion compensating cycles L1, and second dispersion compensation fibers 70 inserted in optical repeating span L2 of the optical repeating amplifier 66 within the first dispersion compensating cycle L1.

[0034] As shown in FIG. 5, the first dispersion compensation fiber 68, similarly to the dispersion compensation fiber 40-6, reduces accumulated chromatic dispersion values of respective wavelengths $\lambda 1 \sim \lambda n$ into a value equal to the product derived from multiplying the Davg by a transmission distance z (Davg × z). As shown in FIG. 5, the second dispersion compensation fiber 70, similarly to the dispersion compensation fibers 40-1~40-5, compensates accumulated chromatic dispersions (and dispersion slopes) of the respective wavelengths $\lambda 1 \sim \lambda n$ so that each accumulated chromatic dispersion of the respective wavelengths $\lambda 1 \sim \lambda n$ after the dispersion compensation varies at an incline of the Dlocal according to a distance z in the first dispersion compensating cycle L1.

[0035] Similarly to the first embodiment, the optical transmission fiber 64 comprises for example a single mode optical fiber having a zero dispersion wavelength at a 1.3 μm band. It is also applicable that the optical transmission fiber 64 in the second dispersion compensating cycle, specifically in one repeating span, comprises a single mode optical fiber having the zero dispersion wavelength at the 1.3 μm band (e.g. an optical fiber of a chromatic dispersion value +18 ps/nm/km) and a minus dispersion optical fiber or a plus dispersion optical fiber with a small dispersion value connected to the single mode fiber, and then the minus dispersion optical fibers 70 for compensating the dispersion slopes and chromatic dispersions are connected to the fiber 64. It is also preferable to gradually change the chro-

such modified optical receiver 62. A wavelength demultiplexer 72 demultiplexes the signal light from the optical transmission line 54 into components of the respective wavelengths λ1~λn. The demultiplexed signal light of the respective wavelengths λ1~λn input signal light detectors 76-1~76-n through dispersion compensators 74-1~74-n. Each dispersion compensation amount of the dispersion compensators 74-1~74-n is individually controlled so that the accumulated chromatic dispersions of the respective wavelengths becomes a predetermined constant value. When the accumulated chromatic dispersions of the respective wavelengths λ1~λn differ one another after the dispersion compensations by the dispersion compensation fibers 68 and 70 on the optical transmission line 54, the accumulated chromatic dispersions of the respective wavelengths can be equalized to a constant value by the dispersion compensators 74-1~74-n.

[0044] Explained above is an example in which the accumulated chromatic dispersion increases in the plus direction. However, obviously, the present invention is also applicable to a case that the accumulated chromatic dispersion increases in a minus direction.

[0045] The dispersion compensator can comprise a chirped fiber grating as well as the above-mentioned SCDCF, and moreover can comprises an optical planar circuit in addition to the fiber types.

[0046] In the above, although the embodiment of the two-stage dispersion compensation was entirely described, a dispersion compensation of a three-stage and over also brings equal or even better operation advantages. It is preferable that the accumulated chromatic dispersion is compensated to zero on the middle point of the optical transmission line.

[0047] As readily understandable from the aforementioned description, according to the invention, the satisfactory long haul transmission characteristics can be realized and at the same time the dispersion control becomes easier. Especially, the invention brings excellent transmission characteristics in WDM transmission.

[0048] While the invention has been described with reference to the specific embodiment, it will be apparent to those skilled in the art that various changes and modifications can be made to the specific embodiment without departing from the spirit and scope of the invention as defined in the claims.

Claims

1. A dispersion compensating optical transmission line comprising:

   a plurality of optical transmission fibers for transmitting signal light;
   at least one first dispersion compensator disposed at a first dispersion compensating cycle for compensating an accumulated chromatic dispersion of the signal light so that an average chromatic dispersion has a first desired value; and
   a plurality of second dispersion compensators disposed at a second dispersion compensating cycle shorter than the first dispersion compensating cycle for compensating the accumulated chromatic dispersion of the signal light so that the average chromatic dispersion has a second desired value, the absolute value of which is larger than that of the first desired value.

2. A dispersion compensating optical transmission line comprising:

   a first dispersion compensation interval having a first optical transmission fiber for transmitting signal light and a first dispersion compensator for compensating an accumulated chromatic dispersion of the signal light so that an average chromatic dispersion has a first desired value; and
   a plurality of second dispersion compensation intervals continuously disposed before the first dispersion compensation interval, each of the second dispersion compensation intervals having a second optical transmission fiber for transmitting the signal light and a second dispersion compensator for compensating an accumulated chromatic dispersion of the signal light so that the average chromatic dispersion has a second desired value, the absolute value of which is larger than that of the first desired value.

3. A dispersion compensating optical transmission system comprising:

   an optical transmitter for outputting signal light;
   at least one first dispersion compensator disposed at a first dispersion compensating cycle for compensating an accumulated chromatic dispersion of the signal light so that an average chromatic dispersion has a first desired value;
   a plurality of second dispersion compensators disposed at a second dispersion compensating cycle shorter than the first dispersion compensating cycle for compensating an accumulated chromatic dispersion of the signal light so that the average chromatic dispersion has a second desired value, the absolute value of which is larger than that of the first desired value; and
   an optical receiver for receiving the signal light propagated on the optical transmission fiber.

4. The dispersion compensating optical transmission line of claim 2 wherein the second transmission fiber in the second dispersion compensating interval comprises a plurality of optical fibers whose

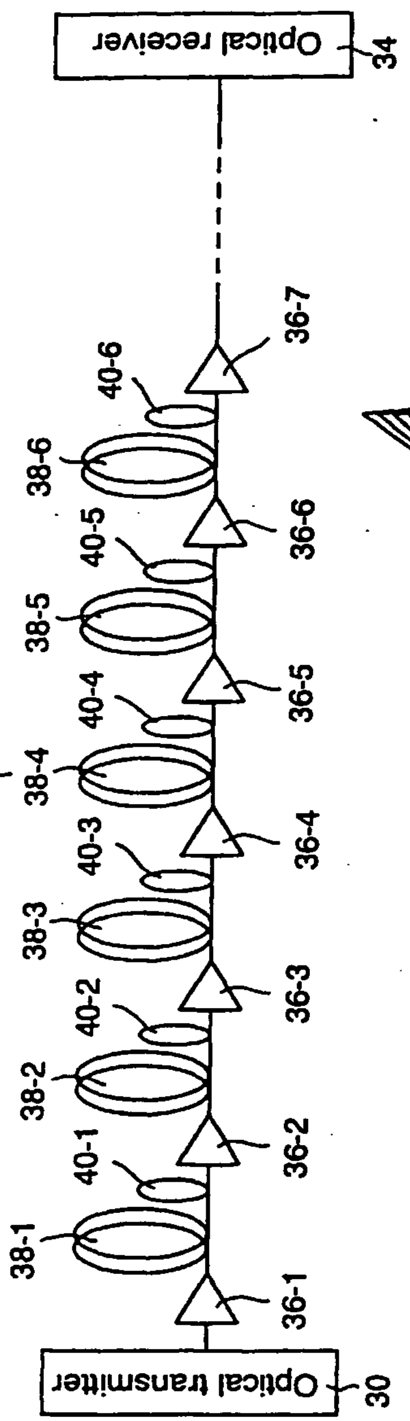

Optical transmitter
30
36-1
38-1
40-1
36-2
38-2
40-2
36-3
38-3
40-3
36-4
38-4
32
40-4
36-5
38-5
40-5
36-6
38-6
40-6
36-7
Optical receiver
34

FIG. 1 (A)

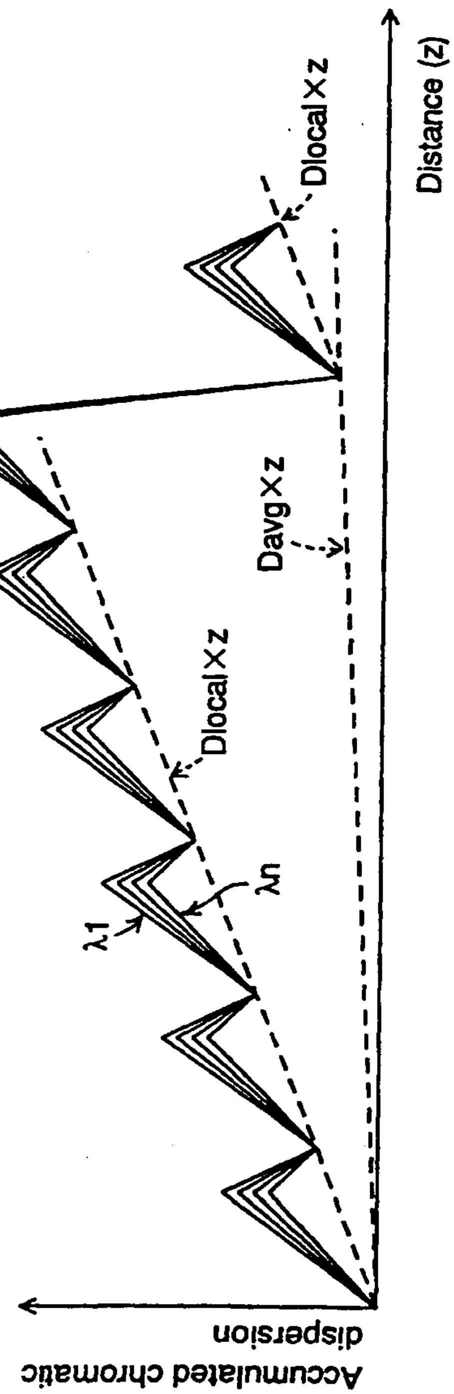

Accumulated chromatic dispersion
λ1
λn
Dlocal×z
Davg×z
Dlocal×z
Distance (z)

FIG. 1 (B)

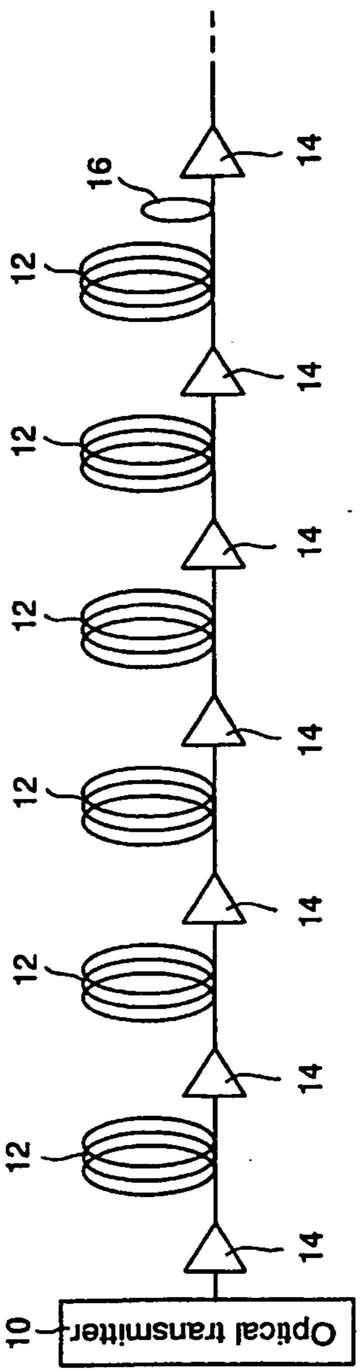

Optical transmitter
10
12
14
16

FIG. 2 (A)

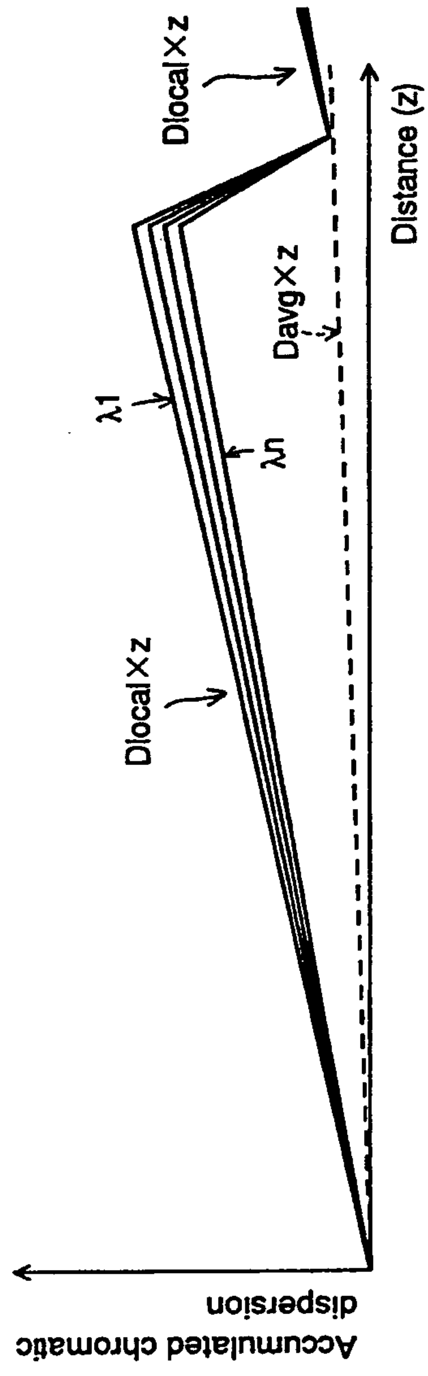

Accumulated chromatic dispersion
Distance (z)
Dlocal×z
Davg×z
λ1
λn

FIG. 2 (B)

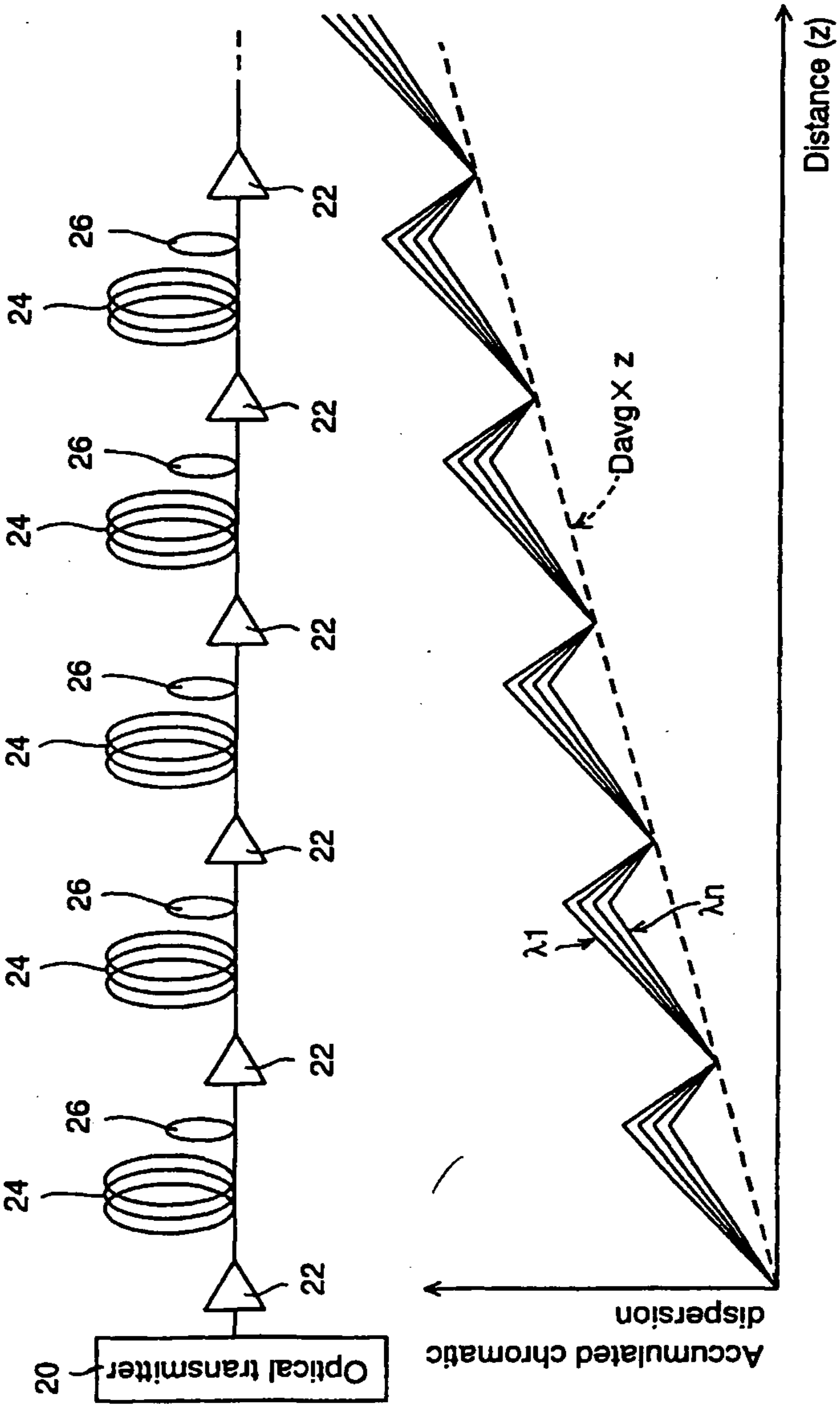
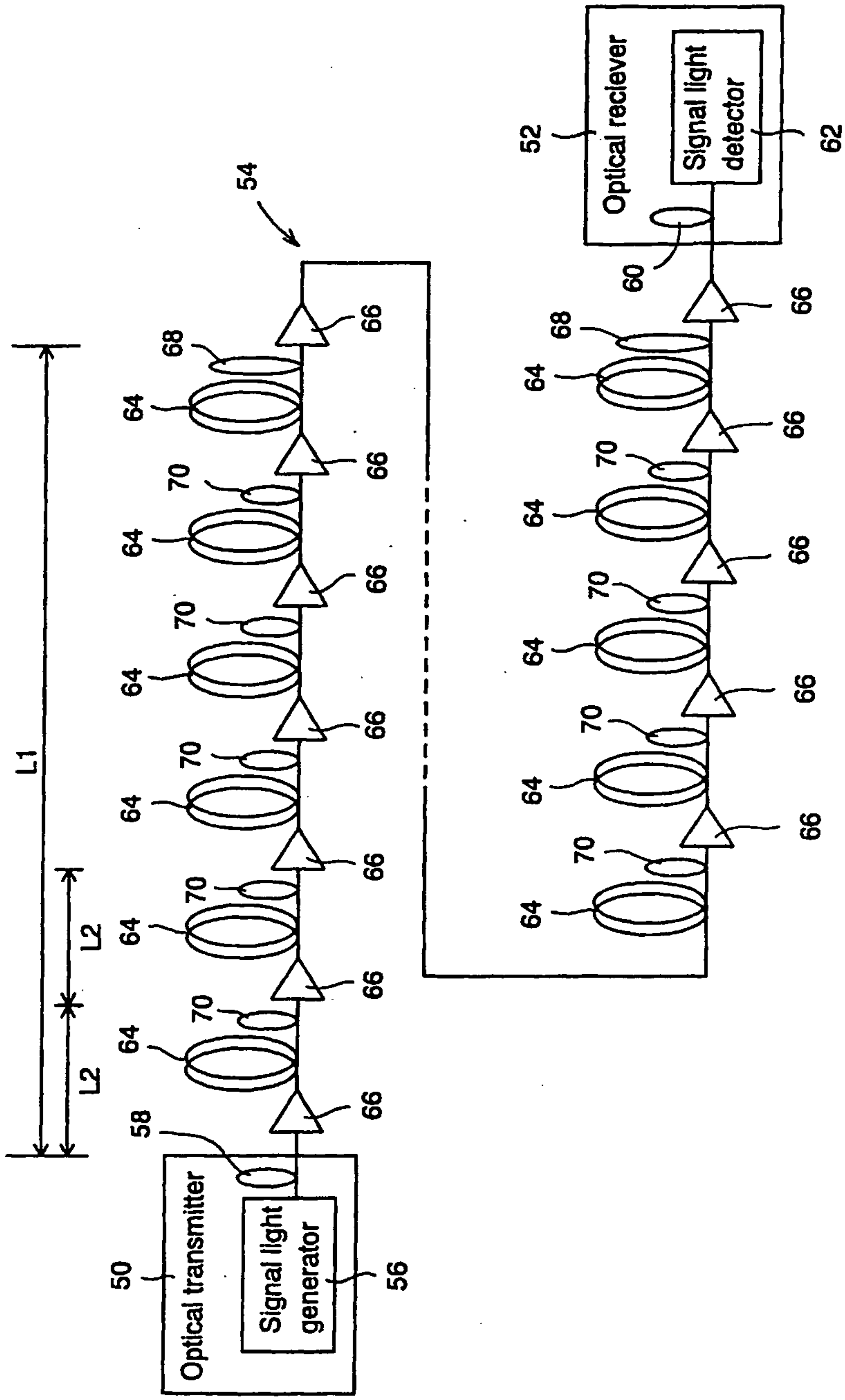

20
Optical transmitter
22
24
26
Accumulated chromatic dispersion
Distance (z)
Davg × z
λ1
λn

FIG. 3 (A)

FIG. 3 (B)

FIG. 4



50
Optical transmitter
Signal light generator
56
58
L1
L2
L2
64
66
70
68
54
52
Optical reciever
Signal light detector
62
60

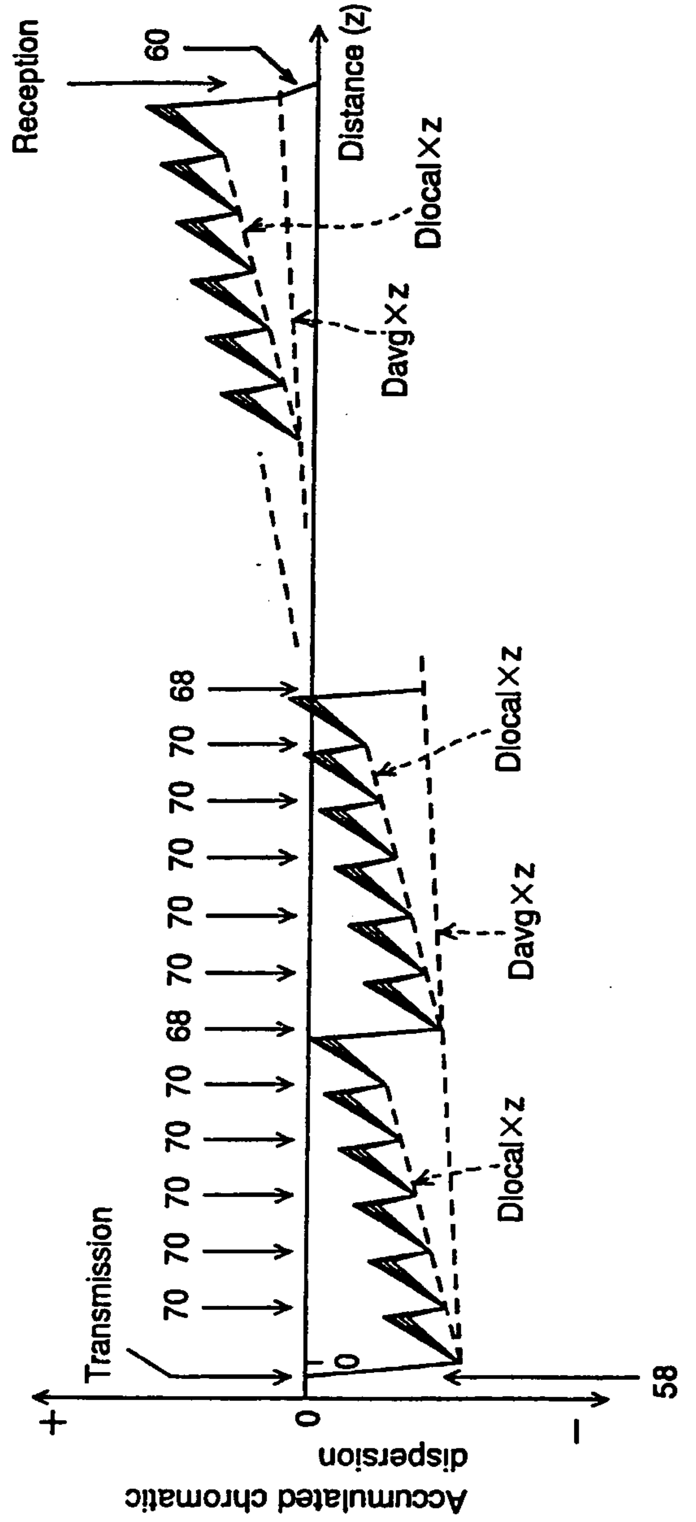

Reception
60
Distance (z)
Dlocal×z
Davg×z
Transmission
70
70
70
70
70
68
70
70
70
70
70
68
0
58
Dlocal×z
Davg×z
Dlocal×z
+
0
−
Accumulated chromatic dispersion

FIG. 5

FIG. 6

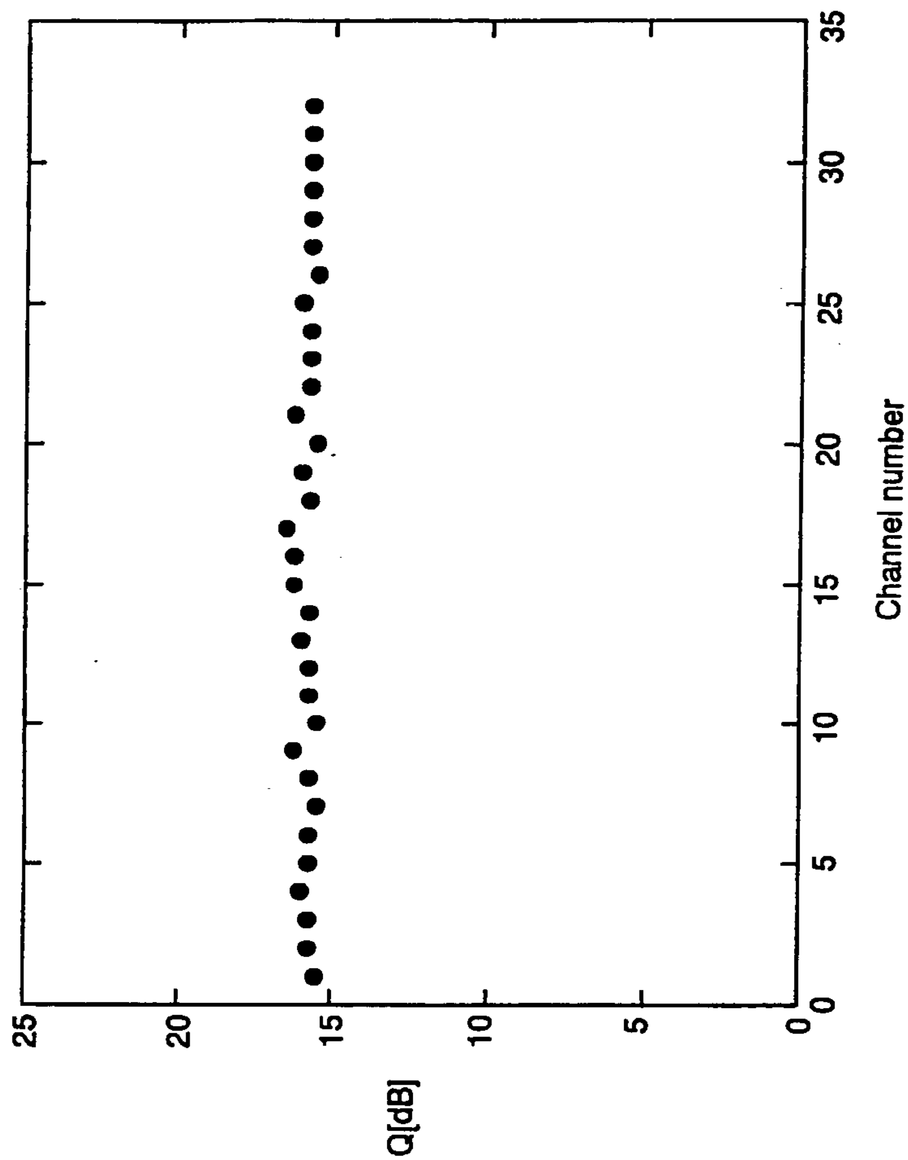


FIG. 7

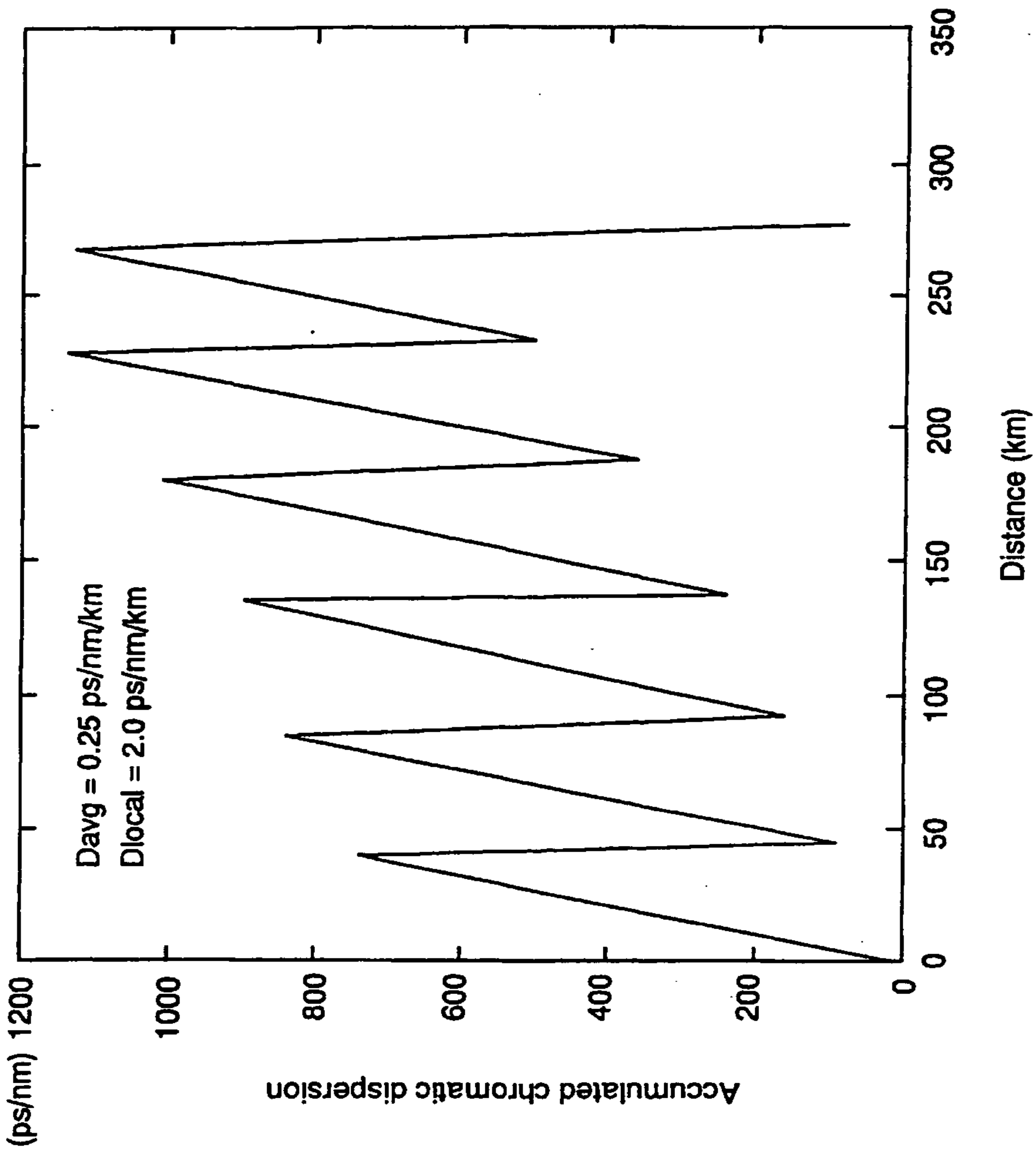
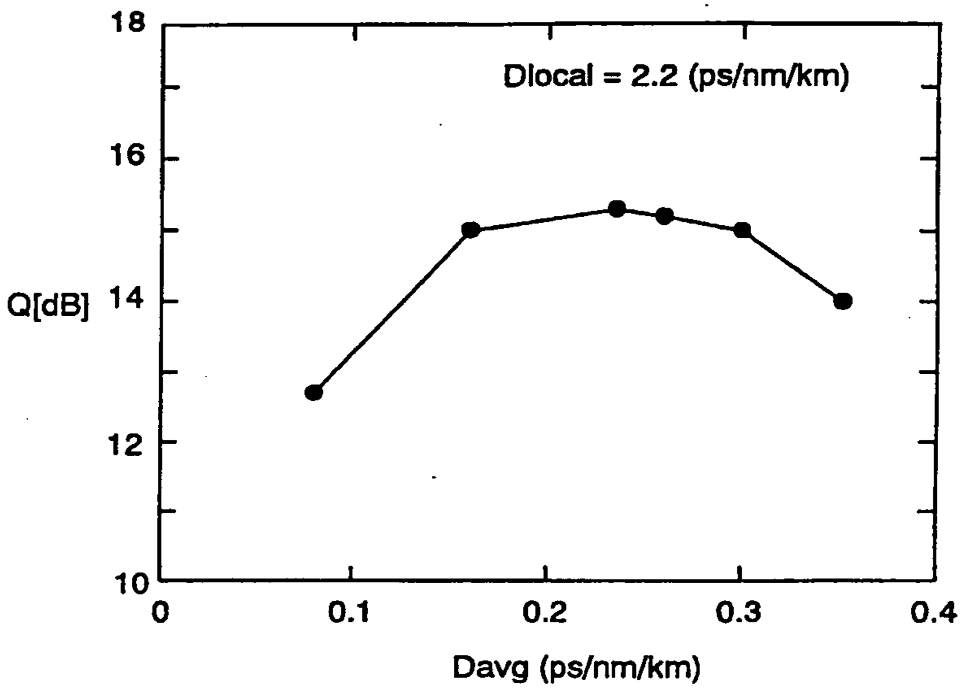

Davg = 0.25 ps/nm/km
Dlocal = 2.0 ps/nm/km
Accumulated chromatic dispersion
(ps/nm)
0
200
400
600
800
1000
1200
0
50
100
150
200
250
300
350
Distance (km)

FIG. 8



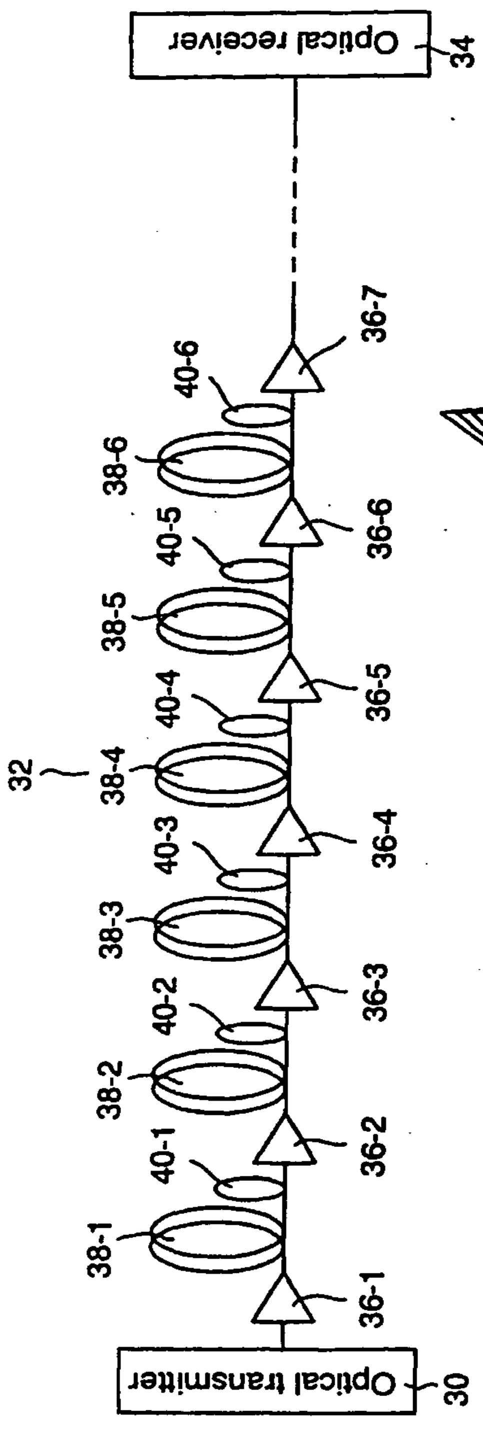

Optical transmitter
30
36-1
38-1
40-1
36-2
38-2
40-2
36-3
38-3
40-3
36-4
38-4
32
40-4
36-5
38-5
40-5
36-6
38-6
40-6
36-7
Optical receiver
34

FIG. 1 (A)

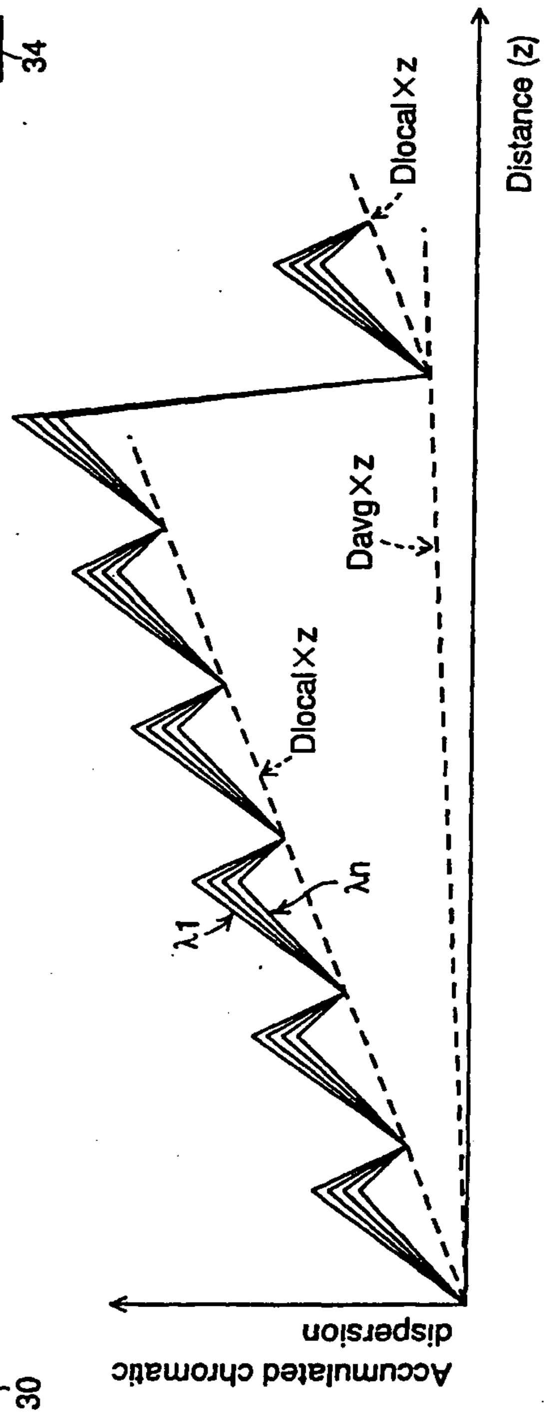

Accumulated chromatic dispersion
λ1
λn
Dlocal×z
Davg×z
Dlocal×z
Distance (z)

FIG. 1 (B)

FIG. 9

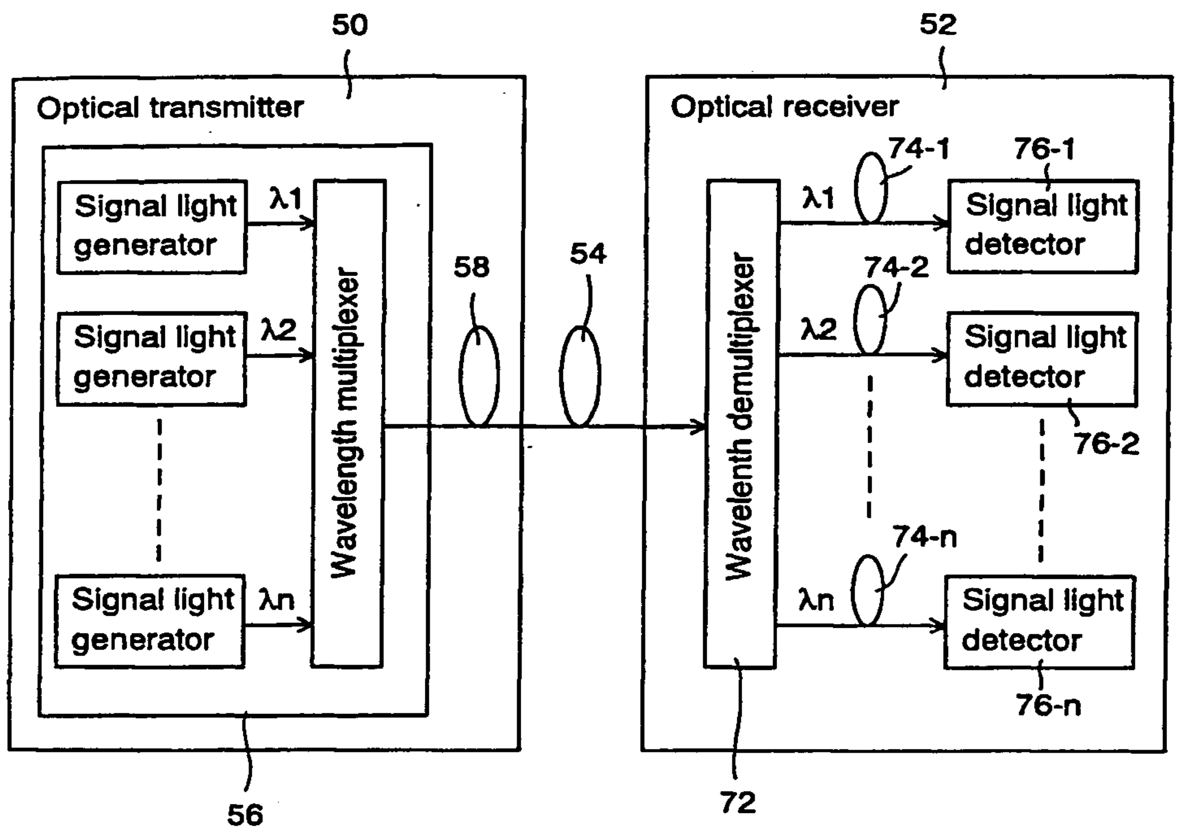

50
52
Optical transmitter
Optical receiver
Signal light generator
Signal light generator
Signal light generator
λ1
λ2
λn
Wavelength multiplexer
58
54
Wavelenth demultiplexer
λ1
λ2
λn
74-1
74-2
74-n
76-1
76-2
76-n
Signal light detector
Signal light detector
Signal light detector
56
72

FIG. 8

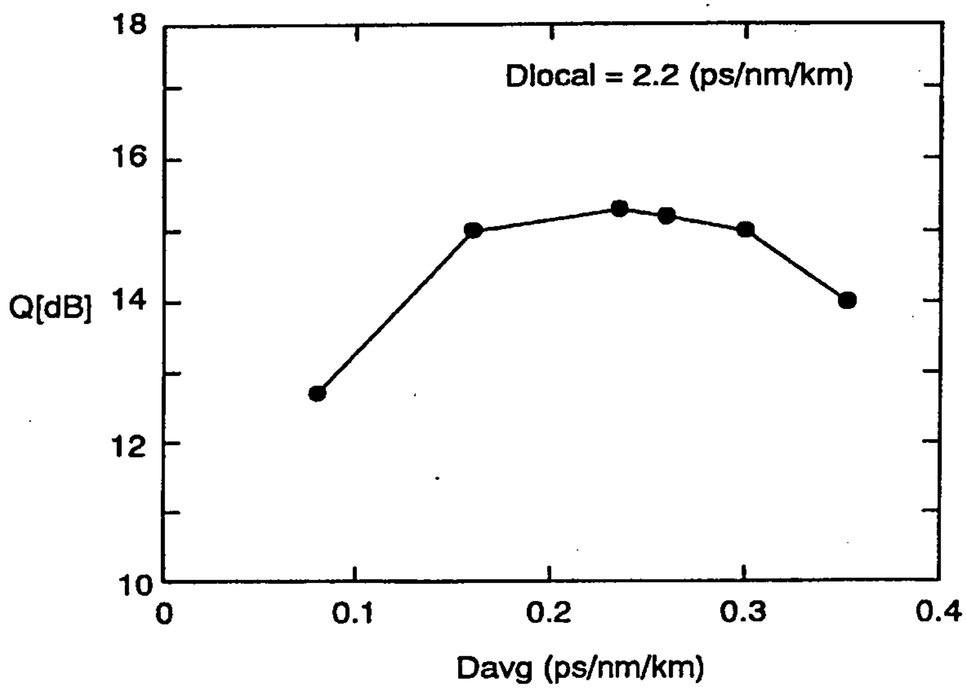
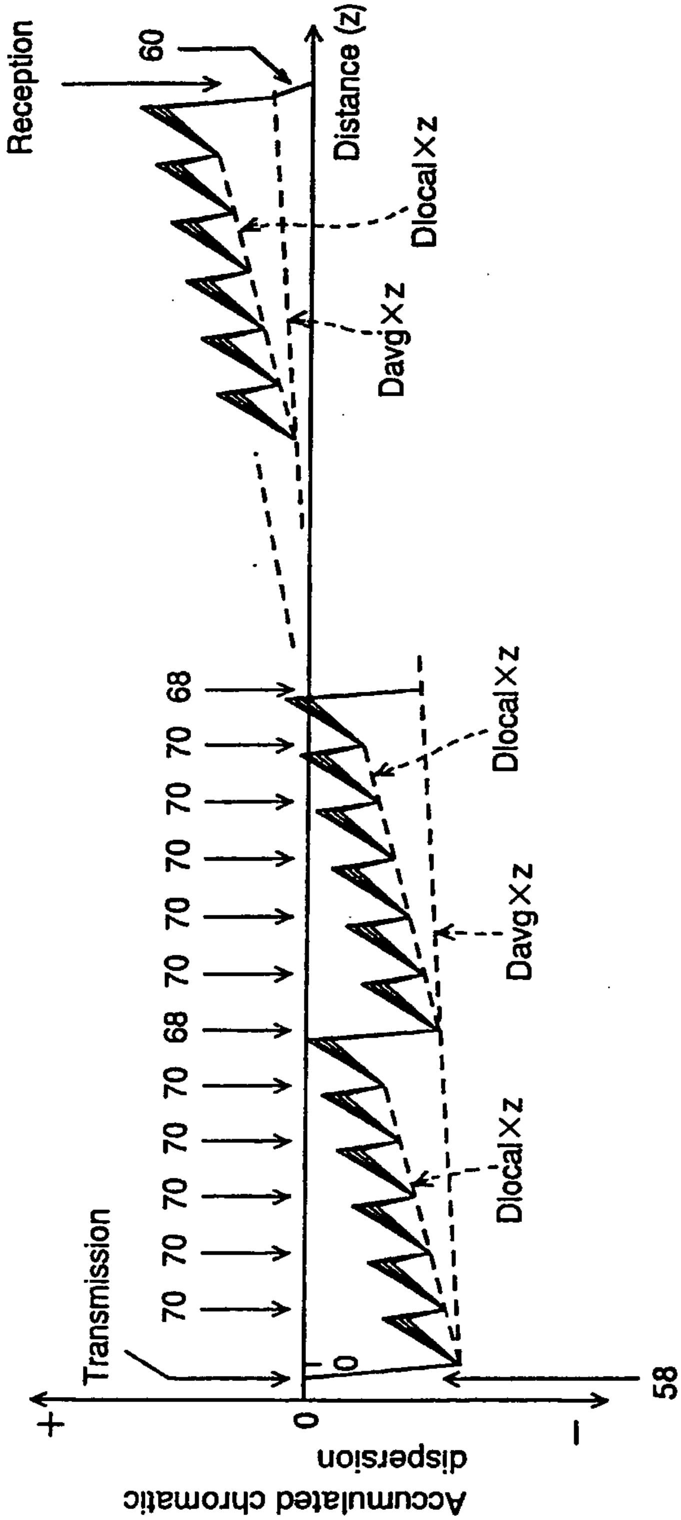


FIG. 5



Reception
60
Distance (z)
Dlocal×z
Davg×z
68
70
70
70
70
70
68
70
70
70
70
70
Transmission
0
58
+
0
-
Accumulated chromatic dispersion

FIG. 7

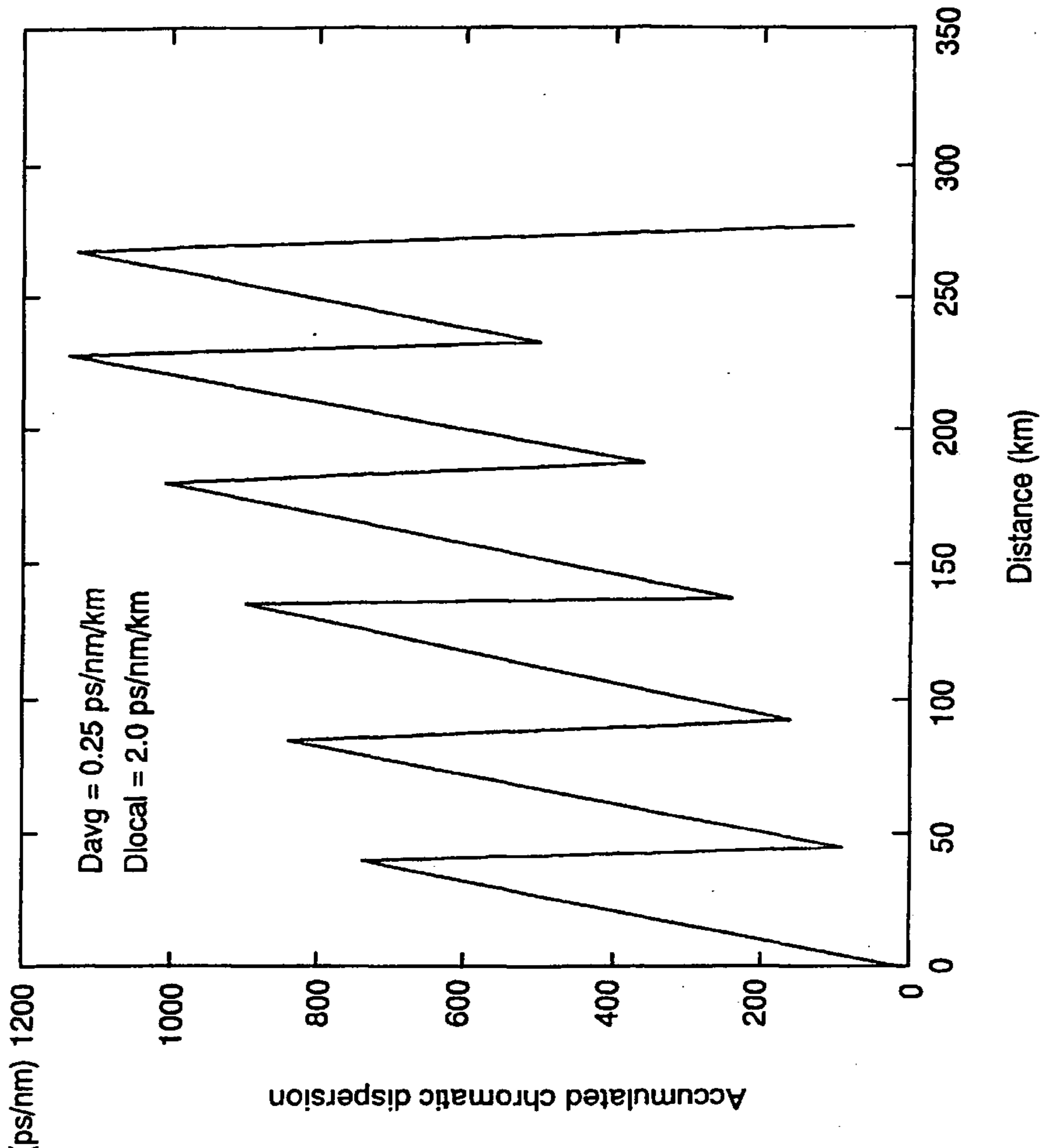

Davg = 0.25 ps/nm/km
Dlocal = 2.0 ps/nm/km
Accumulated chromatic dispersion
(ps/nm)
0
200
400
600
800
1000
1200
Distance (km)
0
50
100
150
200
250
300
350

FIG. 6

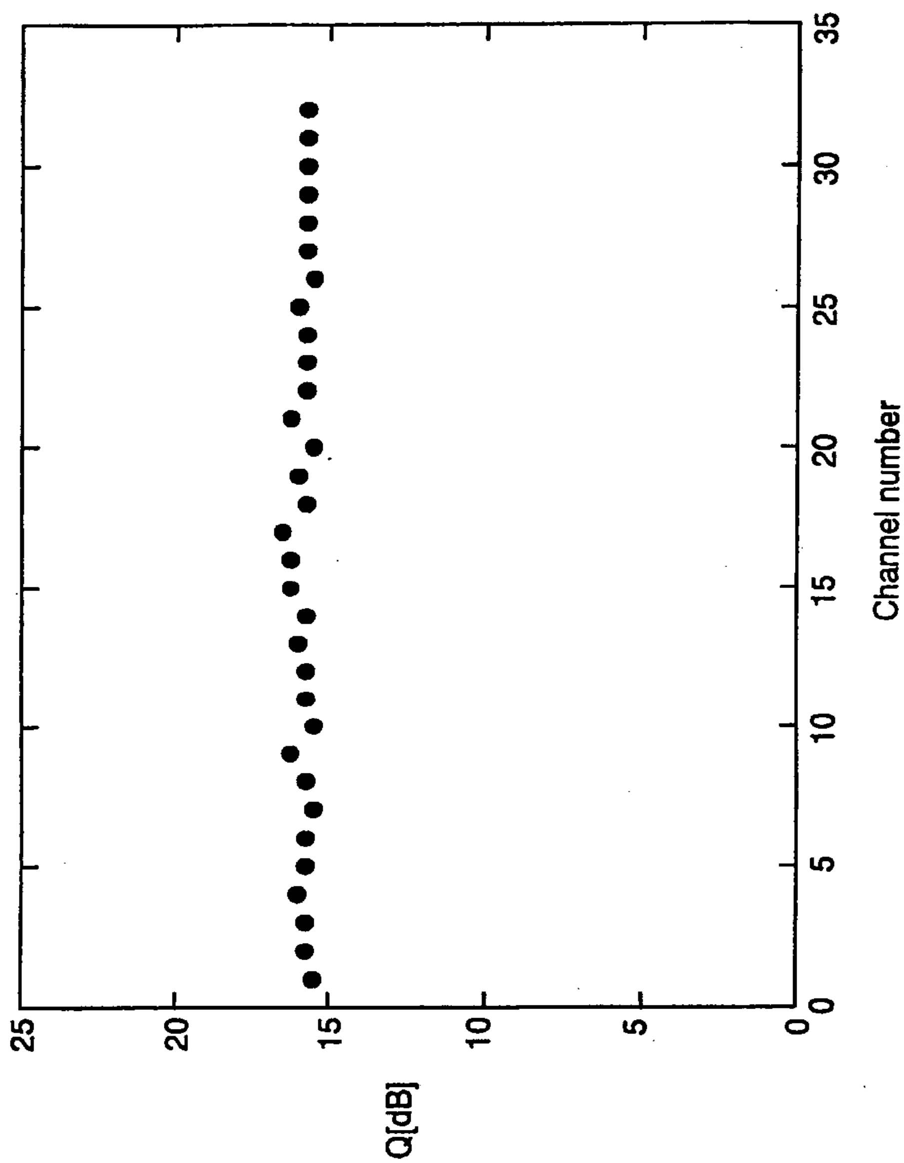
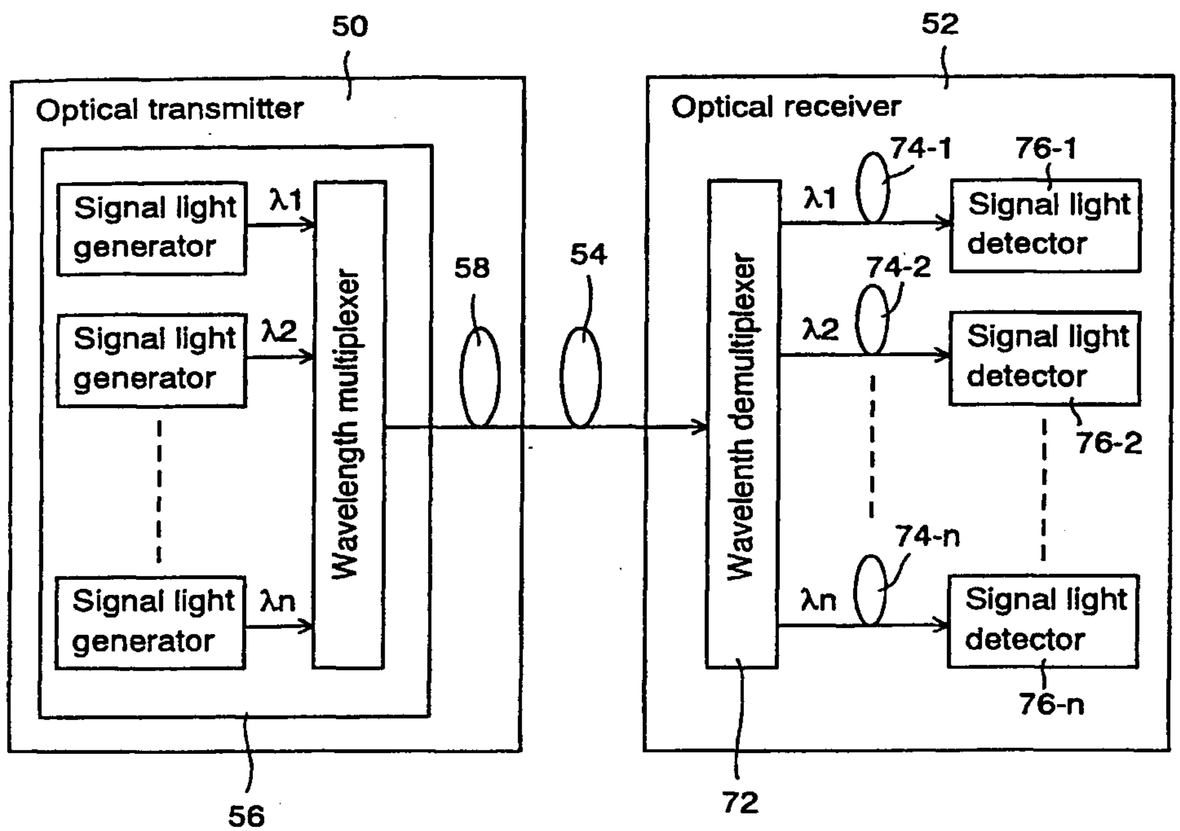


FIG. 9


50
52
Optical transmitter
Optical receiver
Signal light generator
Signal light generator
Signal light generator
λ1
λ2
λn
Wavelength multiplexer
58
54
Wavelenth demultiplexer
λ1
λ2
λn
74-1
74-2
74-n
76-1
76-2
76-n
Signal light detector
Signal light detector
Signal light detector
56
72